AL.2.1993-143
c.2

RESIDENTIAL MAKE-UP AIR SUPPLY AND PREHEAT UNIT

CANADIANA

APR 14 1993

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

RESIDENTIAL MAKE-UP AIR SUPPLY AND PREHEAT UNIT

May 1992

Prepared by:

Dexon Canada Manufacturing Corporation
Calgary, Alberta

The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

With funding provided by
Alberta Municipal Affairs

ISBN: 0-88654-376-2

Printed on Recycled Paper

FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of Alberta Municipal Affairs. The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

The Program offers assistance to builders, developers, consulting firms, professionals, industry groups, building products manufacturers, municipal governments, educational institutions, non-profit groups and individuals. At this time, priority areas for investigation include building design, construction technology, energy conservation, site and subdivision design, site servicing technology, residential building product development or improvement and information technology.

As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied. Comments and suggestions on this report are welcome. Please send comments or requests for further information to:

Innovative Housing Grants Program
Alberta Municipal Affairs
Housing Division
Research and Technical Support
16th Floor, CityCentre
10155 - 102 Street
Edmonton, Alberta
T5J 4L4

Telephone: (403) 427-8150

Acknowledgements

The success of this investigation is attributed to the cooperation of the following team members and their respective area of responsibility:

Henry Dumonceaux	Managing Director
Lawrence Dumonceaux	Construction and Technical Assistant
Bill Ho	Electronic Technician
Tang Lee	Technical Advisor
Doris Pearn	Secretary and Bookkeeping
Franco Wu	Electronic Designer

Mr. Nabil Mansour began with this project but discontinued after the first phase. Invaluable advice was provided by Mr. Dave Whitten and Mr. Derek Tsang, project officers with the Innovative Housing Grants Program, Alberta Municipal Affairs.

Digitized by the Internet Archive
in 2015

https://archive.org/details/residentialmakeu00dexo

TABLE OF CONTENTS

Chapter **Page No.**

List of Tables iii

List of Figures iii

Executive Summary iv

1.0 Introduction 1
- 1.1 Background 1
- 1.2 Previous Work 2
- 1.3 Preview of Report Organization 2

2.0 Establishment of Overall Design Parameters 2
- 2.1 Functional Considerations 3
  - 2.1.1 Prevent Chimney Backdrafting 3
  - 2.1.2 Improve Indoor Air Quality 4
  - 2.1.3 Control Indoor Humidity 4
- 2.2 Operational Considerations 4
- 2.3 Component Configuration 6

3.0 Test Equipment 6

4.0 Development of Generic Components 8
- 4.1 Fan 11
- 4.2 Heating Element 13
  - 4.2.1 Type of Element 13
  - 4.2.2 Length of Element and Contact Time 13
  - 4.2.3 Positioning of the Element 14
  - 4.2.4 Power Requirements 15
  - 4.2.5 Operating Temperatures and Service Life 16
- 4.3 Controls 17

5.0 Prototype Construction, Testing and Unit Enhancement 18
- 5.1 Prototype D1 18
  - 5.1.1 Features 18
  - 5.1.2 Tests and Results 19
- 5.2 Prototype D2 19
  - 5.2.1 Features 19
  - 5.2.2 Tests and Results 19
- 5.3 Prototype D3 21
  - 5.3.1 Features 23

5.3.2 Tests and Results 23
5.4 Prototype D4 25
5.4.1 Features 25
5.4.2 Tests and Results 25
5.5 Final Features 25

6.0 Costs 27

6.1 Production Cost Estimate 27

6.2 Cost of Installation 27

6.3 Operating Costs 28
6.3.1 Airflow Rates 28
6.3.2 Energy Consumption 30
6.3.3 Power Consumption Comparisons 31

7.0 Conclusions and Recommended Future Development 32

7.1 Conclusions 32

7.2 Recommended Future Development 33

8.0 References 34

Appendix A Domestic Heater Controller Prototype A1

Appendix B Schematic of Control Logic B1

List of Tables

Table 1: Minimum Outdoor Temperatures for Various Airflow Rates 16
Table 2: Estimated Component Cost of MUA Unit 27
Table 3: Airflow Rates 29
Table 4: Estimated Daily Airflow Rates 29

List of Figures

Figure 1: Airflow When the Furnace is Not Operating 5
Figure 2: Airflow When the Furnace is Operating 5
Figure 3: Schematic Plan of Test Chamber 8
Figure 4: Uneven Coil Spacing to Minimize Hot Spots 9
Figure 5: Air Feedback Loop 10
Figure 6: Fan Speed Varies According to Operating Conditions 12
Figure 7: Parallel Heating Coils Causes Uneven Heating 14
Figure 8: Angled Heating Coil Intercepts Airflow 14
Figure 9: Power Requirements to Heat Outdoor Air to 18 degrees Celsius at Various Airflow Rates 15
Figure 10: Control compartment with Logic and Other Components in D1 17
Figure 11: Schematic of Prototype D1 18
Figure 12: Fan Downstream 20
Figure 13: Fan Upstream 20
Figure 14: Velocity Gradient at 20 L/s 21
Figure 15: Velocity Gradient at 65 L/s 22
Figure 16: Prototype D2 (above) and D3 22
Figure 17: Enlarged Control Chamber in Prototype D3 23
Figure 18: Temperature Gradient Without Mixing Vanes 24
Figure 19: Temperature Gradient With Mixing Vanes 24
Figure 20: Schematic View of the Make-Up Air Unit 26

Executive Summary

Negative air pressure is often caused by the operation of home exhaust appliances such as hood fans and bathroom exhaust fans. A dangerous result of negative air pressure is chimney backdrafting. Backdrafting occurs when lethal carbon monoxide (CO) fumes from the fireplace and furnace are sucked into the house through the chimney. The safety of the occupants of the home is severely compromised when backdrafting occurs.

As many as 150 people in Canada died from backdrafting related CO poisoning between 1973 and 1983. Several dozen died from asphyxiation as a result of poorly vented dwellings. Recently, Canada Mortgage and Housing Corporation (C.M.H.C.) studies discovered one in three houses with combustion units (fireplaces, gas furnaces, wood stoves, etc.) suffer some degree of backdrafting. This can be attributed to negative air pressure being generated within the houses.

Poor air quality conditions encountered during backdrafting cannot be avoided with conventional air supply fans and electric heaters. The unique problem of backdrafting can be eliminated with a make-up air fan and heater unit working on the principle of balancing the indoor air pressure. The development of a make-up air (M.U.A.) unit was intended mainly to improve indoor air quality but through which reduction of building material and furniture outgassing, radon gas build up, and formaldehyde fumes is logically expected. In addition, the M.U.A. unit was destined for regulation of indoor relative humidity in attempting to minimize damages that can be caused by excessive indoor humidity build up.

This project involved the design, construction, and testing of various prototypes of residential M.U.A. fan and heater units. The units were designed with the capability of varying airflow rates and heat into a home. The design also took into consideration the equalizing air pressure differences between the inside and outside of a building, and made provisions to incorporate an air pressure transducer which is not yet commercially available at this time. Therefore humidity control was chosen as an interim control strategy.

The prototype designs presented in this report were based on an existing sewage lift station heater currently manufactured by Dexon Canada Manufacturing Corporation. The principle behind the sewage lift station M.U.A. unit was used as the prototype design at a test site in the Gift Lake area. This allowed the unit to be observed under different heating and humidity conditions. This unit provided long term site experience that identified a number of design changes for subsequent make-up air unit development.

Four prototype make-up air units were tested in a climate controlled chamber. Tests indicated the final prototype is capable of providing the variable airflow necessary to maintain neutral or slightly positive air pressure, thus eliminating chimney backdrafting. The unit is safe, durable, and is not affected by frost or condensation. Modular components make the unit easy to service and maintain.

Initially, the M.U.A. unit can be expected to retail for $550, inclusive of the yet-to-be developed air pressure transducer. Sales volumes will ultimately determine the final retail price. For a typical home, installation cost will be approximately $200. The cost is reasonable given the sophistication of the unit, and the need for the device. Net energy costs for preheating fresh air through the make-up air unit are estimated to be $130 per year.

The final prototype was submitted to the Canadian Standards Association (C.S.A.) for comments. Recommendations were incorporated into a refined prototype. Full testing by C.S.A. requires installing an air pressure transducer and should be considered necessary future work for the completion of the make-up air unit.

Houses are built to increasingly higher airtightness standards as a means of reducing heating fuel consumption. The resulting lack of air changes compromises the quality of the indoor air, which can affect the comfort and health of the occupants. Furthermore, the increase in indoor humidity has increased the formation of condensation, which not only develops into mould but damages furnishings, finishes, and building materials. The make-up air unit developed in this project can prevent serious health hazards from chimney backdrafting and other indoor pollutants. In addition, the M.U.A. unit can control the amount of indoor humidity to levels that do no cause damage to a building's structure.

1.0 Introduction

1.1 Background

During the years 1974 to 1984, more than 150 fatalities in Canada were caused by chimney backdrafting [CMHC, 1986]. Injuries and smoke damage to property were not reported. With the advent of more airtight houses and the popularity of counter-top exhausts, conditions that promote chimney backdrafting have increased, and so consequently have the dangers.

Airtight houses are becoming increasingly common. While airtightness can decrease the cost of heating and cooling, it also results in the need for adequate ventilation. Proper air heating and circulation require outside air. Provision of make-up air through natural leakage and with passive ducts has proven inadequate in many circumstances. These commonly used methods often result in backdrafting with naturally aspirated heating appliances, particularly if the make-up air ducts are undersized or blocked. The purpose of the make-up air unit (MUA) is to supply preheated fresh air to houses in a mechanically controlled manner to prevent chimney backdrafting. The unit will improve indoor air quality, and dehumidify houses.

The fans and electric heaters that are currently available to the market do not address the problems encountered with airflows, temperature, or operating conditions in airtight environments. Furthermore, these devices are limited in detecting small differential air pressure changes, and hence hamper its optimum functions.

In a recent report for Canada Mortgage and Housing Corporation (CMHC) entitled "Improved Make-Up Air Supply Techniques", Buchan Lawton Parent Ltd. described a conceptual device operated by an air pressure sensitive switch that used a supply fan and electric heater to maintain a safe level of negative pressure. In terms of performance and cost, this device rated higher than nineteen other design variations. At the time of this report, this device is not commercially available.

The objective of this project was to address these problems by designing, constructing, testing, and evaluating a residential make-up air fan and heater unit that can significantly reduce the problems encountered with airtight environments. The overall goal was to produce a market-ready prototype unit. The requirement for a special differential air pressure transducer to operate the unit was recognized for optimum performance, but was not included in the scope of this project.

1.2 Previous Work

Prior to the beginning of this study, a compact make-up air unit (MUA) was assembled and tested in Gift Lake, Alberta for another project [Lee, 1991]. The unit used a sewage lift station heater components, including the DH2 and DH4 controllers from Dexon Canada Manufacturing Corp., and was modified to accommodate controls from a dehumidistat and an outdoor temperature cutoff. The purpose of the MUA was to reduce indoor relative humidity through ventilation. The unit was built with the following features:

- axial AC fan with electric heating element for frost control;
- 3.8 kW 240 Volt, electric element for heating supply air;
- infinite modulation to meet heating demand;

- adjustable supply air temperature;
- automatically or manually activated whenever dehumidistat indicates relative humidity above 20%;
- thermostat controller able to disable unit whenever outdoor temperature above 10°C and;
- high temperature cutoff.

The unit was preset to heat the intake air up to 17°C while the dehumidistat was set at 20% relative humidity. An outdoor temperature sensor was installed to disable the unit at 10°C.

The Gift Lake unit was monitored from September 25, 1989 to mid January, 1990 and provided invaluable site installation experience. The purpose of that unit was limited to controlling high indoor humidity. A considerably more complex set of controls and components is required for a new make-up air unit to solve the problems of chimney backdrafting. The Gift Lake unit, therefore, was taken as the prototypical starting point for the work of this project.

1.3 Preview of Report Organization

This report is organized in sections that describe:

- establishment of prototype design;
- test equipment;
- development of generic components; and
- prototype construction and testing.

Individual sections describe the different prototypes, their operating characteristics, and the testing methods that were used during the course of this project.

After describing the design, construction, and testing of the four prototype units, the report discusses a preliminary cost evaluation of the make-up air unit. Finally, the report discusses recommendations for future developments to the unit.

2.0 Establishment of Overall Design Parameters

Based on market research*, the make-up air (MUA) unit was designed for an airtight house with the following characteristics:

- single family dwelling;
- located on the Canadian prairie;
- typical kitchen and bathroom exhaust vents;
- medium efficiency forced air furnace;
- natural air leakage rate from about 0.25 and to 0.3 air changes per hour; and
- family of two adults and two children.

The pilot project at Gift Lake, Alberta provided the base model for the prototypes. From the test observations at this location, it was concluded that the proposed units would require control mechanisms for:

- air temperature;
- fan speed;
- heating capacity; and
- airflow configuration

Additionally, it was concluded that the MUA unit must be as maintenance free as possible, and that essential safety measures (such as high temperature heating element cutoff) must be addressed in the design.

In the process of establishing the design parameters of the prototype unit, all the above characteristics were considered, and were grouped primarily into three categories, namely functional, and operational features, and component configuration. Details of parameter determination and selection are described in the following subsections.

* The market for the proposed make-up air unit was investigated. Several studies confirmed the target market, and its potential [Buchan, Sheltair, Unies, Lee 1987, Newton].

2.1 Functional Considerations

According to the identified need, the unit design should include the capability of varying airflow rate and heat, and equalizing air pressure differences between the inside and outside of a building.

The MUA unit design would include a temperature controller that would enable the unit to reduce cold drafts, which are common to current ventilation systems with forced-air furnaces. A major function of the MUA unit was to supply outdoor air to prevent chimney backdrafting, as well as to improve indoor air quality and in turn a possible reduction of radon gas, and other toxic elements found in airtight environments. Another notable benefit of the MUA unit is that it brings in cool and dry outside air, which reduces indoor relative humidity and the resulting condensation build up, thereby reducing damage to the internal structures of the building.

With an adequate supply of preheated fresh air through the make-up air unit to houses, the prevention of chimney backdrafting, reduction of damaging condensation, improvement of air quality and dehumidification of the homes are possible.

2.1.1 Prevent Chimney Backdrafting

A balanced supply of outdoor air would counteract negative air pressure resulting from the operation of fireplaces, exhaust fans, and combustion heaters, thereby reducing the inflow of toxic fumes into a home.

2.1.2 Improve Indoor Air Quality

A continuous supply of fresh air into a home would reduce the build up of air contaminants, such as carbon dioxide (CO_2), radon emissions, formaldehyde fumes, and other toxic and dangerous emissions. At optimum operating speed, a steady airflow of 25 L/s, would provide a constant 1/6th air exchange per hour (in a typical home).

2.1.3 Control Indoor Humidity

The prevention of excessive indoor relative humidity and interstitial condensation from forming in a building envelope would be attainable by drawing drier outdoor air into the house, which displaces humid indoor air through furnace chimneys and exhaust vents. A dehumidistat could be added to control the operation of the unit for humidity control regulation. When the indoor relative humidity rises above a set level, for instance 35 percent, the supply fan increases to maximum speed. This higher speed creates a momentary positive pressure in the house, but this does not force moist air into the building envelope because the humidity is not allowed to build up. Once the make-up air unit has been installed it maintains indoor relative humidity at or below the set level. In Maritime regions, the unit will require longer operation due to the higher outdoor humidity levels.

2.2. Operational Considerations

At the time of development, various types of home heaters and several fresh air electric heaters were considered, and concluded that the following operational and performance should be addressed:

a) airflow range rates using variable fan speeds;

b) air leakage rate when unit is shut off;

c) discharge air temperature control (+/- 2°C);

d) fan speed control;

e) pressure range;

f) heating capacity;

g) safety controls;

h) resistance to frost and moisture in critical components;

i) serviceability and reliability; and

j) cost of manufacturing, installation, operation, and maintenance.

When the furnace is not operating, the make-up air unit preheats fresh air from outside and discharges the heated air into the return air duct. Preheated fresh air moves up the return air duct of the house through the return air intake grille (see Figure 1). The preheated air is also driven through the furnace into the house.

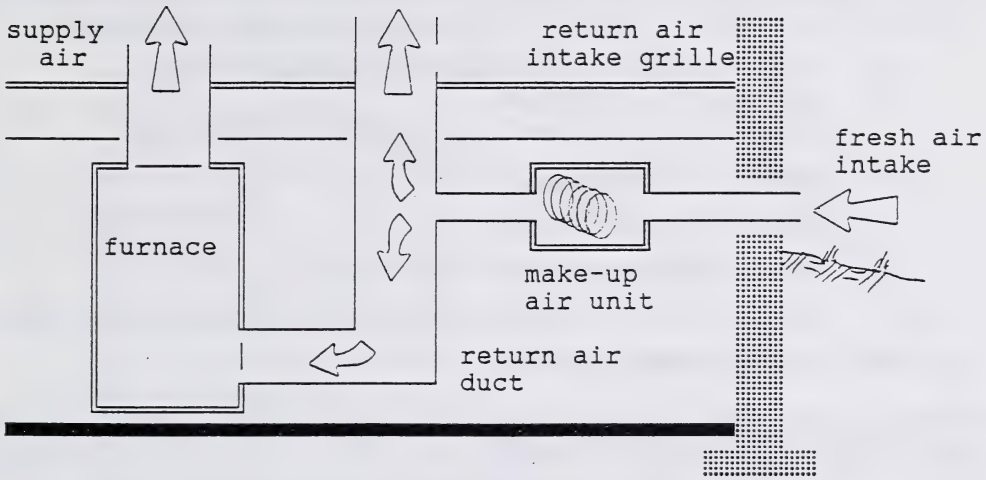


Figure 1: Airflow When the Furnace Fan is Not Operating

When the furnace fan is operating, all of the fresh air moves through the furnace before discharging into the house (see Figure 2).

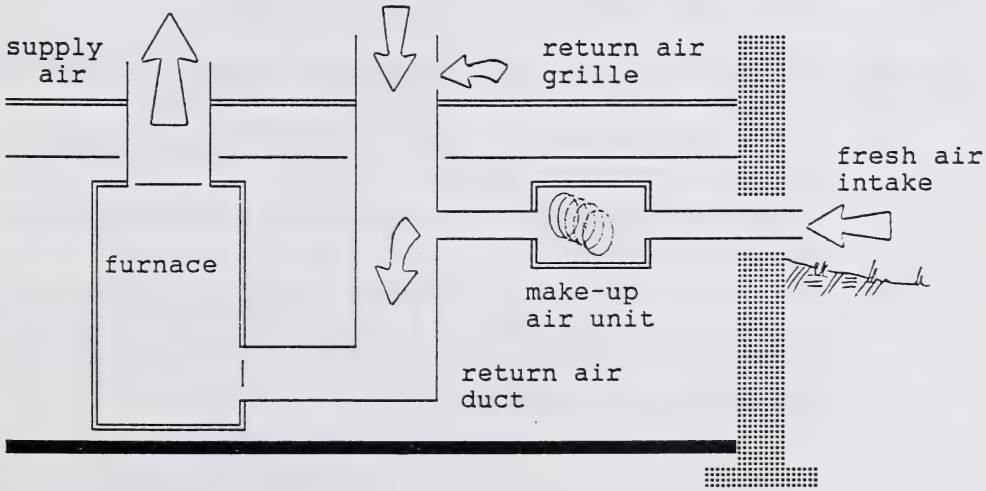


Figure 2: Airflow When the Furnace Fan is Operating

2.3 Component Configuration

Based on the tests and observations of the study on condensation problems at Gift Lake, Alberta it was found the prototype MUA unit must allow for variations in design, which include:

a) fan location (upstream or downstream of heating elements);

b) triac location (cold or hot side);
Note: A triac is a solid-state relay that heats up during operation.

c) heating of motor bearings;

d) electric heating of control cabinet;

e) use of feedback air loop to heat control cabinet;

f) use of feedback air loop to heat main fan when in upstream location; and

g) insulation of duct connection.

Four prototype MUA units would be designed, constructed, and tested. Each of the prototypes would have different component configurations, and be tested for performance. As refinements were made, the prototypes were reconfigured to accommodate the new components, and then re-tested.

3.0 Test Equipment

Each prototype developed for this project was tested in a test chamber. This chamber allowed the units to be tested under an array of uncontrolled and controlled conditions. The same test chamber was used for each prototype. The test chamber allowed ambient conditions to be varied between severe cold and humidity, while at the same time, supplying outdoor air throughout the entire chamber. In addition, it enabled the control and simulation of air pressure.

The purpose of the test chamber was to test the prototypes for functionality in extreme types of winter weather conditions. In addition, it was also the mandate of the tests to:

a) Test individual components to determine performance when subjected to the expected environment conditions within homes.

b) Test two complete working prototypes, and determine performance in relation to the design criteria developed.

c) Based on the performance of the first two prototypes, modify the design and construct two more prototypes. In addition, refine the prototypes for market production and for Canadian Standards Association (CSA) approval.

d) Provide data for CSA evaluation of the unit.

The test chamber was equipped with power, lighting, humidifier, and monitoring instruments. It was constructed with the following specifications:

- access door and monitoring window
- 2.4 m long x 2.4 m wide x 2.1 m high
- vapour and thermal barrier
- access for monitoring equipment
- fresh air inlet
- air exhaust

Observing the performance of the prototypes consisted of:

- Monitoring temperature of air downstream of test chamber, and triac. Temperatures were recorded at regular intervals.
- Recording relative humidity in the test chamber with a hygrothermograph.
- Monitoring airflow speed with a hot wire anemometer.

The following instruments were used for monitoring the prototypes:

1) **Temperature data logger:**

   Model EDC 3020T Thermocouple Logger

   Electronic Controls Design, Inc.

   Mulino, Oregon.

   - programmable for thermocouple types, dwell time and printing interval
   - 40 channel multiplexer
   - type "K" thermocouple wires
   - temperature resolution of 1°C

2) **Hygrothermograph**

   Cole-Parmer N-08368-50

   Temperature resolution +/- 1°C

   Relative humidity, +/- 3% FS.

3) **Hot wire anemometer**

   Model: Thermo-anemometer GGA23S

   Wallac, Alnor, Finland.

4) **Florite air velocity meter**

   Model MLD, Bacharach, Inc., Pittsburgh.

Figure 3 shows a schematic of the test chamber and its principle design features.

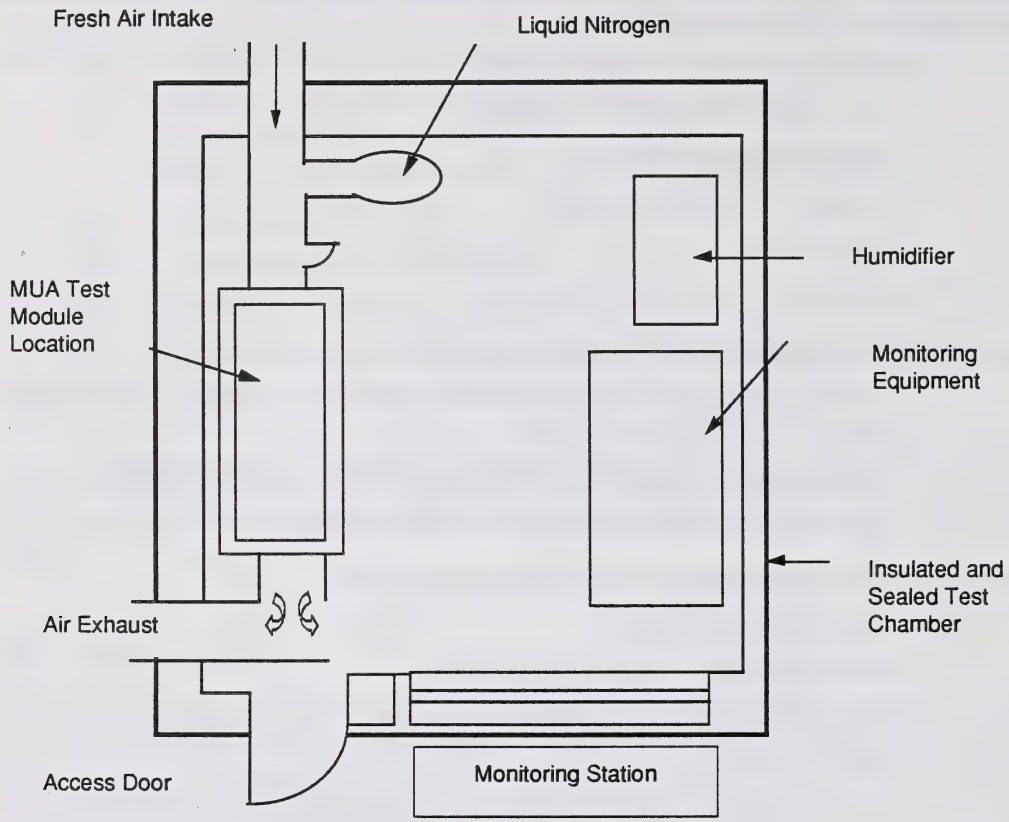


Figure 3: Schematic Plan of Test Chamber

The test chamber also allowed for cold air simulation. To provide thorough coverage of all conditions, the make-up air unit required testing under simulated and varying cold climates. An artificial cooling chamber was designed and constructed for cold temperature testing using liquid nitrogen. Liquid nitrogen was injected into the upstream duct to cool intake air. Temperatures down to -30°C were achieved by controlling the amount of liquid nitrogen discharged into the air stream. Temperatures of the outdoor air supply entering the artificial cooling chamber could be sufficiently lowered when required.

4.0 Development of Generic Components

Before choosing any components for the make-up air unit, each component was assessed to determine its service life and potential for modularization for manufacturing and maintenance. Modular components facilitate servicing and repair. Among the modular components incorporated into the make-up air unit were the fan, heating element, control circuit board, and air filter. The

container was also redesigned to facilitate servicing.

Regardless of the outdoor air temperature, each unit was designed to preheat fresh air to prevent cold drafts into a house. Each of the prototype MUA units was designed with:

- a variable speed fan with a maximum flow rate ranging between 25 - 115 L/s (50 - 240 cfm) at zero static pressure [Buchan]
- a built-in electric heater (4000 Watts, 240 Volts)
- a discharge temperature adjustable from 15°C to 22°C
- modular components for easy replacement and servicing
- a printed solid state electronic control circuit
- high temperature safety cutoff
- automatic operation
- compact and self contained components
- durable components

One of the tests conducted determined the temperature of the electric heating element. Thermocouples were attached at various locations on the heating coil to determine its surface temperatures. With a uniformly wound heating coil, hot temperatures were observed at the mid-span of the coil.

When developing their sewage lift station heaters, Dexon experimented by varying the spaces between the spirals of the heating element. Dexon developed a spacing configuration in the spiral that caused uniform temperatures throughout the length of the heating element, thus, reducing areas of "hot spots".

Based on experience with sewage lift station heaters, the heating element was configured as shown in Figure 4. The mid span of the coil was placed further apart to eliminate possible hot spot development.

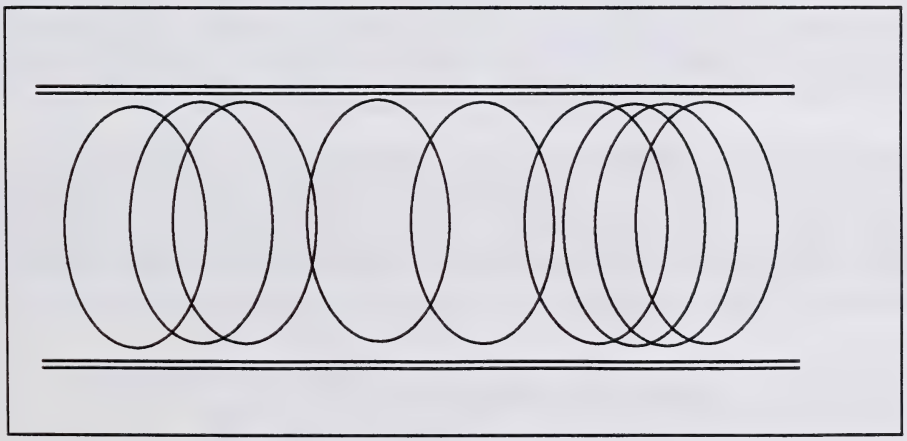


Figure 4: Uneven Coil Spacing to Minimize Hot Spots

In attempting to alleviate motor cold start when fans are located at the upstream side of the heating element, warm downstream air was brought back into the MUA from the downstream side. An air deflector and side cavity was created in the housing unit to provide the air feedback loop (see Figure 5).

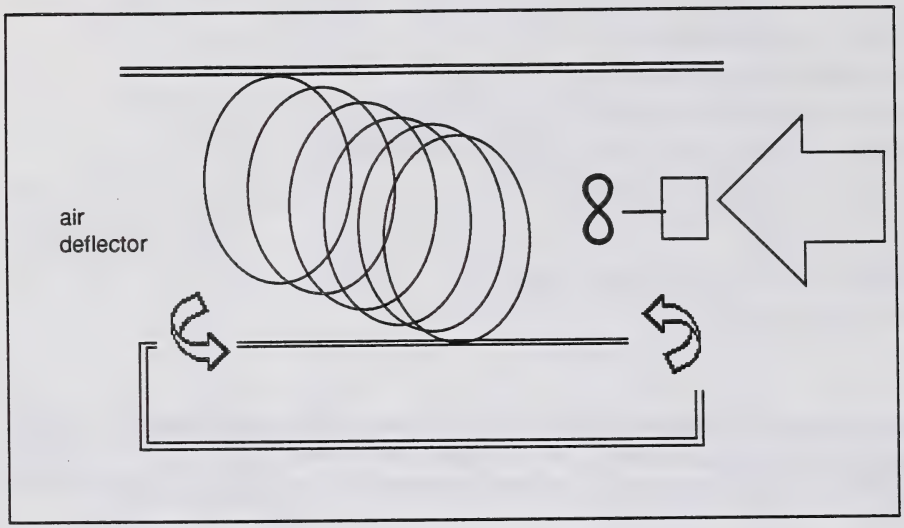


Figure 5: Air Feedback Loop

An 8°C rise in intake air temperature was achieved with the air feedback loop. Unfortunately, tests conducted with the air feedback loop indicated an approximate 25% loss in airflow that required compensation with a larger fan.

When the make-up air unit was not operating, the fan was exposed to the cold outdoor air. The advantage of the air feedback loop was apparent only after the fan and heater were operating. At that time, the warm air feedback would warm up the fan moderately faster, than without the feedback loop. At idle speed, the feedback loop was too slow to be advantageous. Given the marginal benefit of the air feedback loop, and considering complications arising from loss of efficiency, the air feedback loop was rejected.

The triac is a solid state relay for powering the fan and the heating element in the make-up air unit. When electrical current is supplied to the fan or heating element the respective triac heats up. When operating the make-up air unit, the initial triac temperature rose to 51°C, which was well below the 125°C maximum allowable temperature for this component. The design philosophy is to lower the triac temperature for the purpose of extending its service life. Prototype D3 and D4 designs address the triac temperature.

4.1 Fan

Article 9.33.3.1 of the 1985 Alberta Building Code states:

> "*Dwelling units shall have a mechanical ventilation system capable of providing at least one half an air change per hour during the heating season, based on the interior finish volume of the dwelling unit. The system shall be controlled either manually by a switch or automatically.*"

With a normal room height of 2.44 meters, the maximum floor area is 828/2.44 = 340 m^2. A make-up air unit, with a fan airflow rate of 113 m/s (240 cfm), can ventilate a 340 m^2 house to one half air change per hour.

The average airflow of most common bathroom exhaust fans is rated at 25 L/s, but the actual rate is considerably less [Howell-Mayhew]. The average airflow rate, measured by CMHC, was found to be closer to 15 L/s or 44% of the rated flow. This was attributed to static pressure [Buchan]. For kitchen range-hoods, the average measured airflow rate was 38% of the manufacturer's rated airflow [HRAI]. For residential range-hoods, measured airflow rates were typically between 17 L/s to 55 L/s. When bathroom exhaust and range-hood exhaust operated at the same time, the total airflow rates ranged from 32 L/s to 80 L/s. A fan with a rated airflow of 113 L/s (240 cfm), at no static pressure, was adequate and therefore selected for this make-up air unit.

The maximum house size, which can be ventilated at one half air change per hour (ach), given an electric fan with an airflow rate of 113 L/s, is calculated by:

$$\text{Volume} = \frac{113 \text{ L/s} \times 3.6}{0.5 \text{ ach}}$$

where: 3.6 = conversion from seconds to hours and litres to cubic meters

When very strong exhaust fans (for example, counter top exhaust fans) were used while other exhaust fans were also in use, the combined backdrafting pressure could be greater than the make-up air unit was able to accommodate. This demonstrated that houses with extreme backdrafting problems might require two units. This does not preclude enlarging the size of the unit and the airflow rate if the need is proven. Future development of an air pressure transducer can help determine if the selected fan is adequate for an average house.

A tube axial fan was selected instead of a centrifugal (squirrel cage) fan. The axial fans, which have the advantage of component and interface simplicity, are durable and available in many sizes. Although axial fans were sensitive to static pressure, they were not considered to have any problems when operating essentially under negative pressure in counteracting chimney backdrafts.

The calculated annual cost of maintaining the fan at maximum speed is:

$$\frac{25\text{W} \times 25\text{h} \times 365.25 \text{ d/yr}}{1000} \times \$0.06/\text{kWh} = \$13.15/\text{year}$$

When chimney backdrafting was neither present nor was there a need to control humidity, the make-up air unit operated continuously at a minimal idle speed. The power consumption dropped to 4.5 volts. For smooth idling the fan would run at 6 volts. At this voltage, approximately 8 watts of power is consumed at a speed of about 1200 RPM. Theoretically, the fan would achieve an airflow rate of 40 L/s at zero static pressure; however, the measured airflow rate is closer to 25 L/s.

At idle speed, the fan consumed:

$$\frac{8\ W \times 24\ h \times 365.25\ d/yr}{1000} \times \$0.06/kWh = \$4.20/year$$

Other reasons for maintaining an idle speed on the make-up air unit fan include:

- To prevent reverse airflow through the unit resulting in condensation and freezing. While adding a motorized damper or one-way valve would prevent a reverse airflow, it would however complicate the unit and increase the cost of manufacturing and installation.
- Slight pressurization would help exhaust fumes remaining in the chimney flues.
- Slight ventilation would help maintain air quality.
- Some ventilation would help maintain better control of indoor humidity.
- Reduce unintentional air leakage.

The fan operates in the conditions shown in Figure 6.

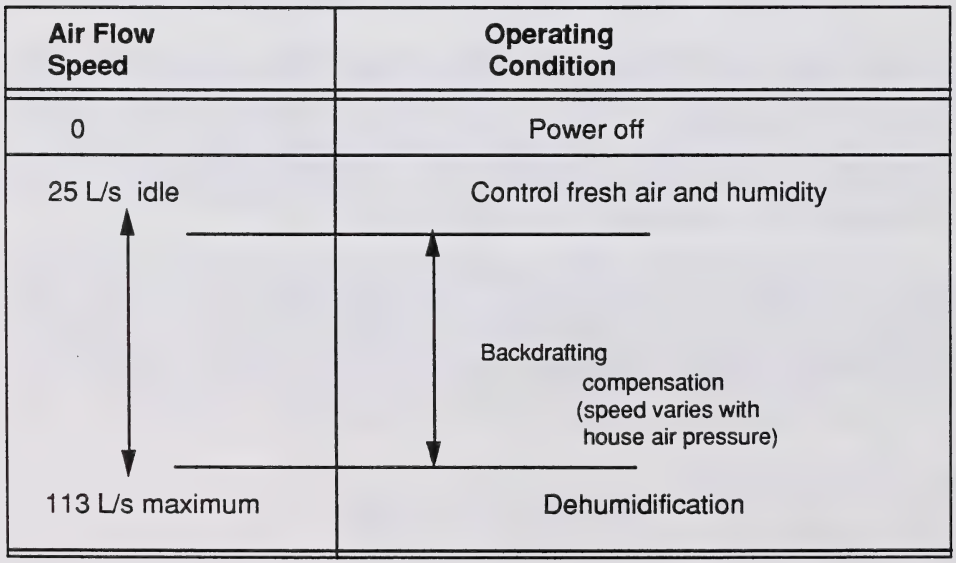


Figure 6: Fan Speed Varies According to Operating Conditions

4.2 Heating Element

The purpose of the heating element is to heat the outdoor air as uniformly as possible. In addition, hot spots on the element must be avoided. Hot spots can reduce the service life of the element. This section describes the investigation that determined the optimum configuration of the heating elements. The following properties and characteristics of a heating element were taken into consideration during the investigation:

- type of element
- length of element and contact time
- position of element
- power requirement
- operating temperature and service life

4.2.1 Type of Element

The type of element used was a tubular incoloy (tick), electric heating element, with a low 3.1 watt/cm^2 density. This element handled low air flow speeds and modulated (evened out) temperatures. This was expected to prolong its service life.

4.2.2 Length of Element and Contact Time

Adequate contact time with the heating element was necessary for uniform heating and effective mixing of cold outdoor air. In prototype D1 and D2, the length of the heat exchanger was 330 mm. In Prototype D3, the heat exchanger was extended to 440 mm to achieve the desired contact time and air mixing.

4.2.3 Positioning of the Element

Positioning the electric heating coil in the middle of the plenum resulted in uneven heating of air flowing across the elements (see Figure 7). The heating coil was angled to intercept as much airflow as possible (see Figure 8).

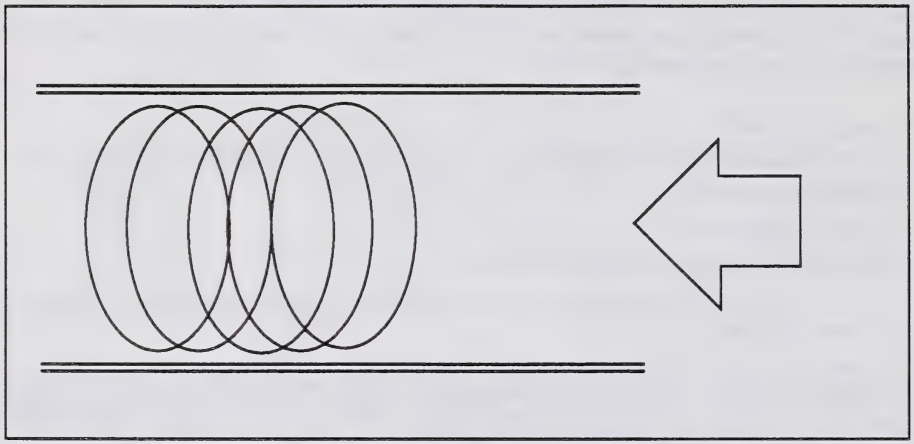


Figure 7: Parallel Heating Coils Cause Uneven Heating

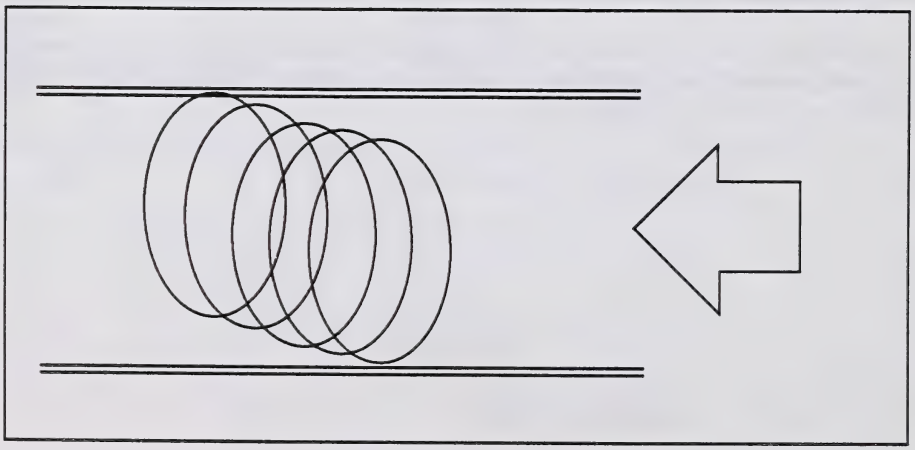


Figure 8: Angled Heating Coils Intercept Airflow

4.2.4 Power Requirements

For electric heating, the required electrical power (kW) to heat outdoor air was calculated with the following equation:

$$kW = \frac{Q(Ts - To)}{785}$$

where:

kW	=	heater capacity (kW)
Q	=	airflow rate (L/s)
T_S	=	supply air temperature (18°C)
T_O	=	outdoor air temperature (°C)
785	=	constant to convert to kW

Based on the above equation, Figure 9 shows the power requirement to heat intake air at various outdoor temperatures from -35°C to 18°C.

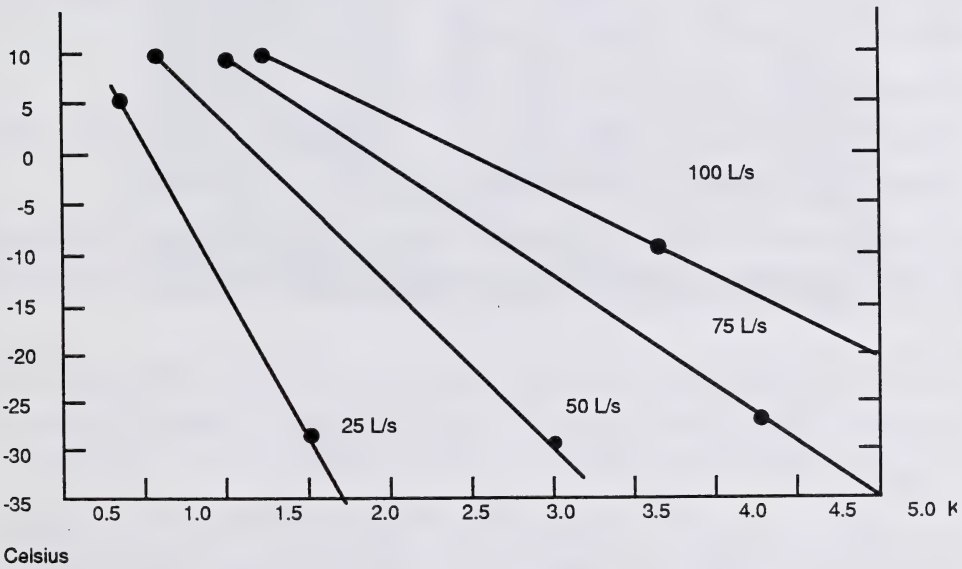


Figure 9: Power Requirements to Heat Outdoor Air to 18°C at Various Airflow Rates

It is unlikely a heater larger than 4000 watts is required. A 4000 watt heater is capable of heating outdoor air to 18°C at various airflow rates, (see Table 1). The make-up air unit, including the electronic controller, was designed to handle 25 amps at 240 volts, which can safely accept a 5000 watt heating element. If the make-up air unit does not have the required heating capacity, two or more make-up air units can be installed.

Table 1: Minimum Outdoor Temperatures for Various Airflow Rates*

50 L/s	-31.8° C
75 L/s	-23.9° C
100 L/s	-13.4° C

* with 4000 W heating element

4.2.5 Operating Temperatures and Service Life

Generally, high heating element temperatures shorten service life (earlier burn-out). Mineral insulated heaters that use traditional alloys for electrical resistance elements are subject to oxidation. This limits service life because the winding wire oxidizes proportionately to the element temperature. If the heater element temperature is known, it is possible to project the life span. At approximately 870°C, estimated life is one year based on the manufacturer's literature [Watlow]. At 820°C, the projected life is three and a half years. With the low operating temperature of 300°C, the heating element in the make-up air unit is so low the estimated life of the heating element would be almost indefinite.

Service life of a heater element can be further extended by:

a) avoiding contact with particulates, such as insects, oils that oxidize on the element, and;

b) minimizing temperature variations during thermal cycling of the elements.

A washable air filter was installed in the make-up air unit. This component allows only outdoor air to come in contact with the heating element. Household dust, grease, vapour, and other particles would not likely be carried across the elements.

Temperature variations in the unit were regulated by a logic controller that set the airflow rate and the heating element temperature, provided the pressure transducer was installed. This prevented the unit from cycling on and off. Given the application and design of the make-up air unit, the service life of the heating element was estimated to be longer than the life span of the house.

In normal operating conditions, with the fan blowing cold air across the heating element, the average surface temperature of the heating element is lower than other controllers (even at an idling speed). The advantage of lower operating temperatures is the extended service life, as explained above.

4.3 Controls

Based on the long term proven success of the sewage lift-station heaters and the performance at the Gift Lake installation, the same solid state control logic for all four prototypes was used, except for the pressure transducer and the dehumidistat capability. For monitoring and testing purposes, some modifications were required (see Appendix A). For example, the logic controller will now accept a signal from a simulated air pressure transducer. This allows the heater element temperature, as well as the fan speed, to be manually controlled.

The control compartment houses the printed circuit boards, triac, power transformer, and other electronic components. Figure 10 shows the control compartment with the logic controller, and other internal components.

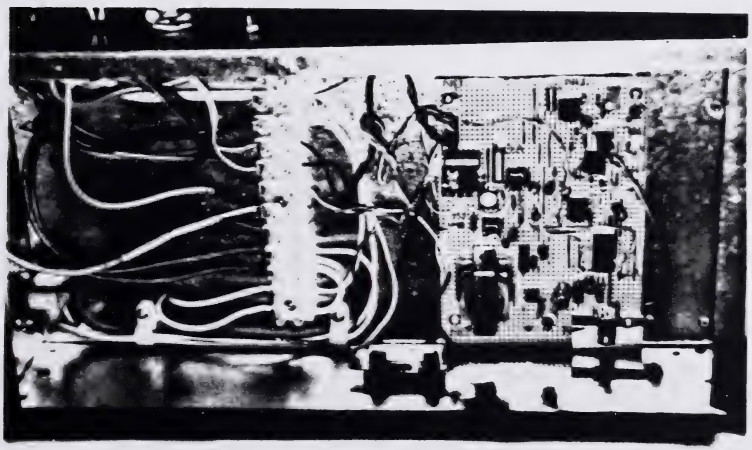


Figure 10: Control Compartment with Logic and Other Components in D1

A downstream air temperature sensor was needed to control the heating element. A semi-conductor sensor was used because of its accuracy, uniformity between sensors, and ease of interfacing with other components in the unit. This sensor detected the temperature of downstream air to regulate and maintain the set temperature. The same sensor acted as a low temperature cutoff at 9°C to 10°C, preventing the intake of cold outdoor air without preheating. In addition to the temperature control sensor, there was an overheat device located at the top of the heat exchanger independent of the temperature controller.

5.0 Prototype Construction, Testing, and Unit Enhancement

Two prototypes, D1 and D2, were built and tested based on the experience and performance of the Gift Lake model. The testing time was reduced by building and testing the prototypes simultaneously. The results of prototypes D1 and D2, provided the criteria for the third prototype, D3. The final refined prototype, D4, was used to develop the potential commercial version. The final prototype was delivered to the Canadian Standards Association (CSA), Edmonton for an evaluation. A fifth prototype was built incorporating suggestions from the CSA, and with further refinements for production purposes.

5.1 Prototype D1

Prototype D1 was constructed using a AC fan and a damper. Although the unit was functional, the fan speed was difficult to regulate to the required speed. This is necessary to make the unit viable.

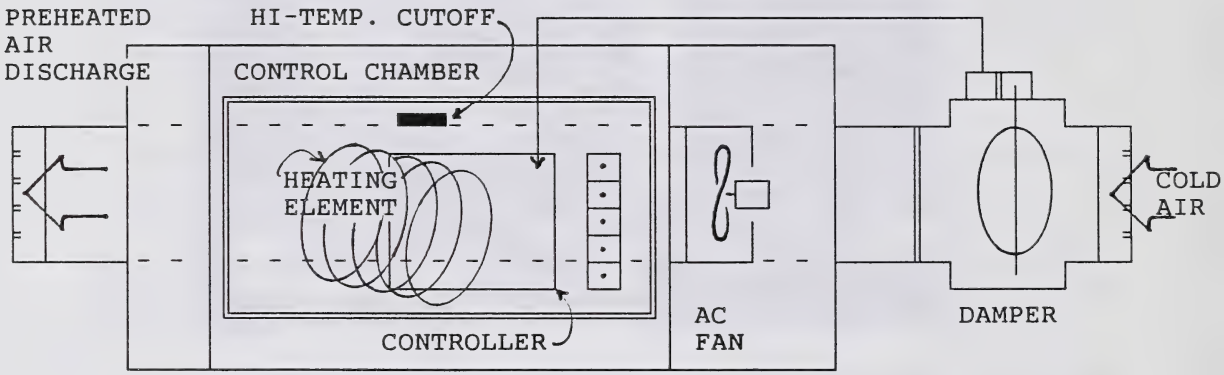


Figure 11: Schematic of Prototype D1

5.1.1 Features

The attempt to create a compact unit resulted in the control compartment of prototype D1 being slightly too small. Although the compartment accommodated all the components, there was inadequate room to allow for proper servicing, and for the eventual installation of the air pressure transducer. Subsequent prototypes were designed with a larger compartment.

5.1.2 Tests and Results

An alternating current (AC) fan was selected and tested under cold outdoor conditions. When tested at -32°C overnight, the fan was cold started in the morning. After a difficult start, the fan warmed up within 5 minutes, although the fan speed remained less than the manufacturer's rated speed. This was not satisfactory for a finished product.

To resolve the problem of cold starts, the fan motor was wrapped with an electric heating cable, heat trace. While this remedy was successful, the additional cost and complexity of the heating cable, along with additional electrical consumption, made it commercially non viable.

In attempting to reduce the AC fan speed, it was found that most AC fans were inappropriate because they were single speed, and were affected by fluctuating power, age, and use. To counteract chimney backdrafting, a variable speed fan was needed to respond to variable indoor pressures. A DC fan provided the variable speed capability that was required.

5.2 Prototype D2

MUA prototype D2 enhanced the features of D1, and eliminated the need for a damper with the use of a continuously running fan that remained at a low idle when not in demand. This prevented the intake of cold air into the unit, and prevented cold drafts. Overall, this design allowed air moving past the down stream sensor to be warmed.

5.2.1 Features

During operation heat created in the triac (relay) must be dissipated. High temperatures would eventually impair the triac's performance and shorten its service life. An aluminium plate mounted to the galvanized metal housing of the make-up air unit acts as a heat sink. In Prototype D2, the triac temperature reached a tolerable 51°C.

5.2.2 Tests and Results

In prototype D2, the unit housing was built to accommodate the fan in either the upstream or downstream from the electric heating element. Tests were conducted with the fans in both locations. In the downstream location, the fan was subjected to warm air previously heated by the heating element. In this position, the potential of overheating existed, despite air flowing across the fan. Some heating occurred after the power ceased due to the thermal lag of the heating element. As a result, the fan was subjected to high temperatures without the cooling effects of air flowing across the fan motor.

When motors are subjected to overheating, the lubricants dry out and the service life of the motor is shortened. Given this possibility, the fan was located upstream of the heating element, but the problem of frost and reluctant cold starts had to be addressed. Both the advantages and disadvantages of locating the fan upstream or downstream of the heating element are summarized in Figures 12 and 13.

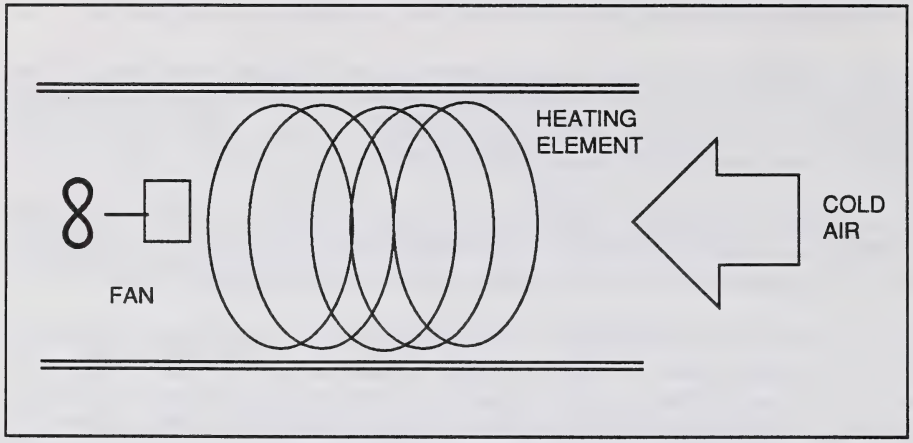


Figure 12: Fan Downstream

Fan At Downstream:

Advantages

- warmed motor, no cold starts
- no frost or condensation on fan

Disadvantage

- can overheat fan
- evaporates or dries lubricants
- shortens service life

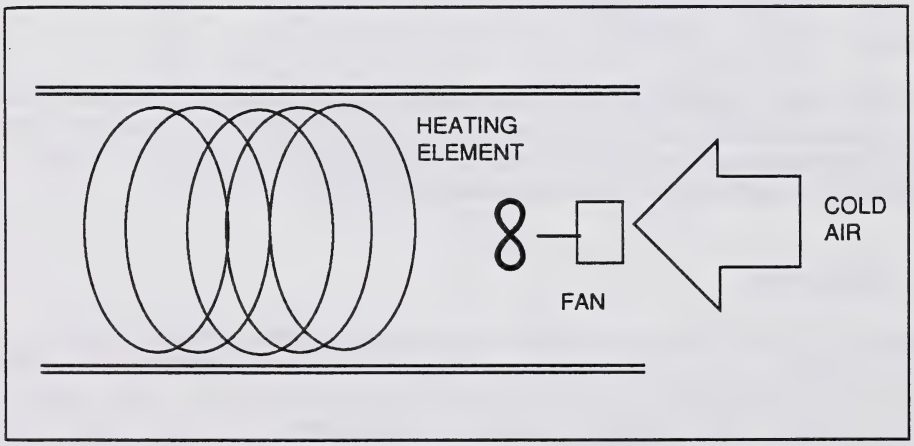


Figure 13: Fan Upstream

Fan At Upstream:

Advantages

- no overheating and the associated problems
- fan is available and operational to -20 °C

Disadvantages

- potential condensation and frost
- cold starts after a power failure

The decision to locate the fan upstream of the heating element, as shown in Figure 13, was based on the need for a durable but safe make-up air unit. Cold starting would not be a problem since D2 was designed to operate with the fan idling.

Uneven airflow was observed on the downstream side of the make-up air unit immediately past the heating element. The uneven airflow created uneven temperature distribution across the discharge duct. In a typical installation, the air would be thoroughly mixed in the air plenum, before discharging into the house; however, the problem of uneven airflow could affect temperature sensors and heating element controls. Mixing the air to achieve uniform air temperatures was an important component of the make-up air unit. The difficulties in maintaining uniform airflow are addressed in section 5.3, Prototype D3.

5.3 Prototype D3

Based on the two earlier prototypes a third make-up air unit was designed (see Prototypes D3 in Figure 16). The modifications of Prototype D3 are described below.

To determine airflow resistance, such as air turbulence and distribution, air velocity across the duct downstream of the make-up air unit was measured. Surface resistance and turbulence were minimal at low speeds. At 20 L/s the velocity profile (shown in Figure 13) indicated even airflow distribution and improved concentric pattern, as well as wide spacing across the velocity gradient.

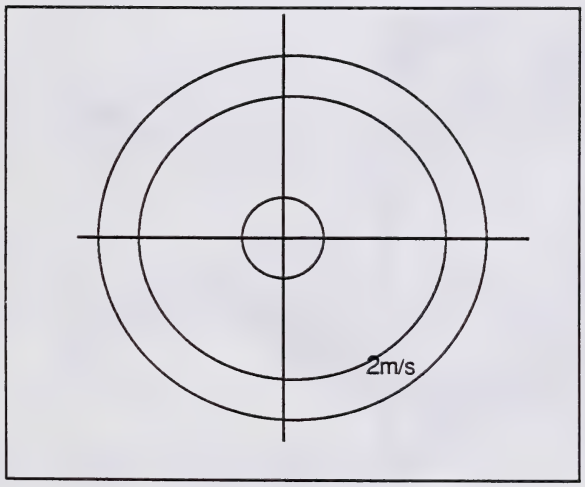


Figure 14: Velocity Gradient at 20 L/s

Figure 15 shows that at higher speeds, such as 65 L/s, there is potential for more air turbulence. This is common in ducts and can help even out the air temperatures. In the D3 prototype, temperature variation was further reduced, as will be addressed in the next section.

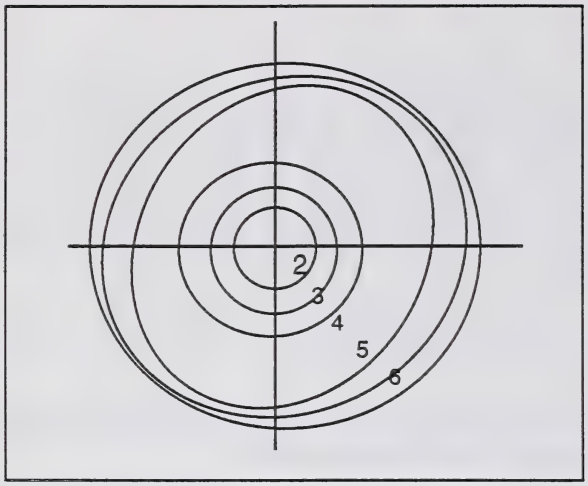


Figure 15: Velocity Gradient at 65 L/s

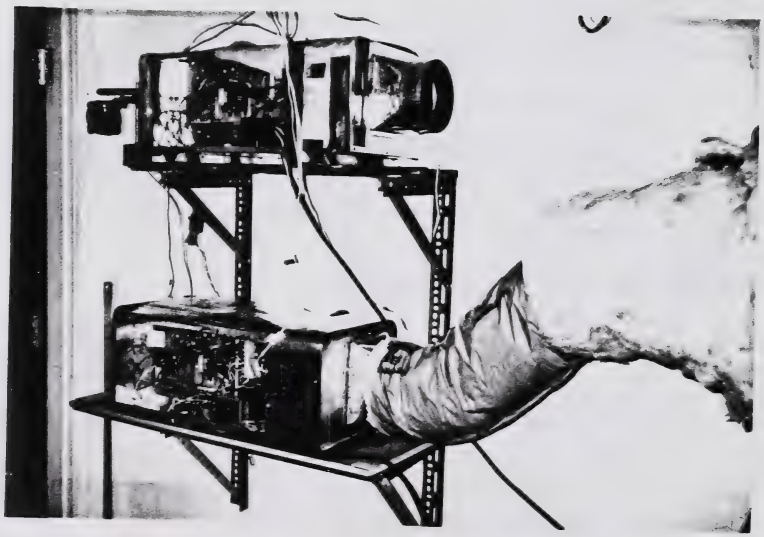


Figure 16: Prototype D2 (above) and D3

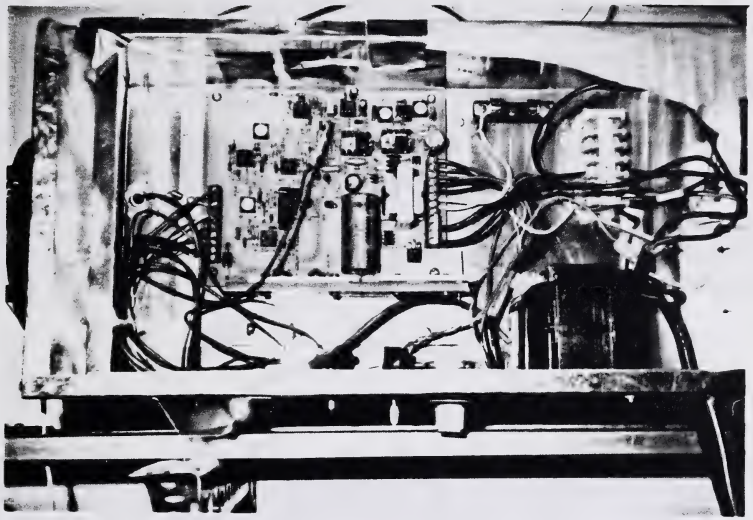


Figure 17: Enlarged Control Chamber in Prototype D3

5.3.1 Features

In prototype D3, a 15% larger aluminium plate, along with the larger control chamber helped further lower the triac's temperature. The resulting temperature was less than 40°C and was considered an excellent operating condition for the triac. In summer, the triac will not operate because the heating element will not be used as often.

As mentioned in section 5.1.1, the control chamber housing the circuit boards and other electronic controls was too small. In Prototype D3, the control chamber was enlarged from 180 mm x 32 mm to 220 mm x 40 mm (see Figure 16). The additional space satisfies CSA requirements, allows for easier servicing, and permits the installation of the future air pressure differential transducer.

5.3.2 Tests and Results

The make-up air unit was installed away from the discharge grille. The increased distance helped mix the air before it discharged into the building.

Positioning the temperature sensor further down the downstream duct where the air had a better mix, enhanced temperature control. It is easier to position the sensor within the make-up air unit, rather than to install a remote temperature sensor elsewhere.

Using variously configured mixing vanes between the fan and heating element, the air temperature discharged out of the make-up air unit becomes more uniform than before (see Figures 18 and 19). Some differential airflow rates and fluctuating temperatures across the duct were still noticeable, but were considered normal and unavoidable.

Figures 18 and 19 show the changes in temperature distribution across the duct under identical airflow rates and average temperature output, before and after mixing vanes are installed.

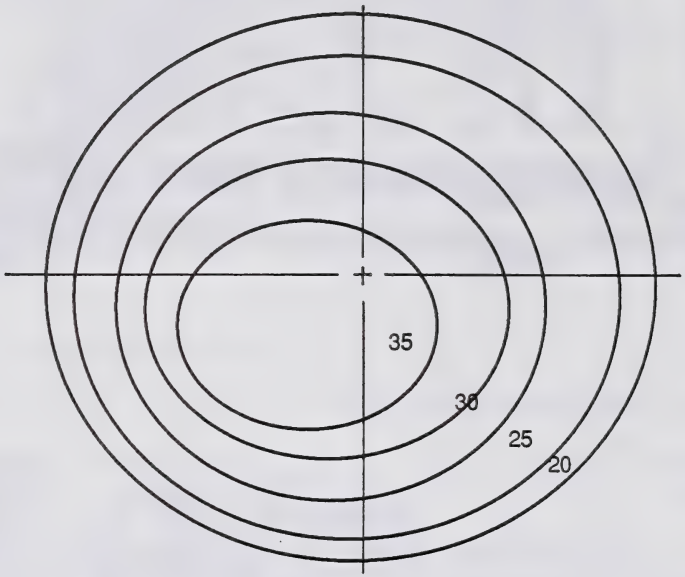


Figure 18: Temperature Gradient without Mixing Vanes (°C)

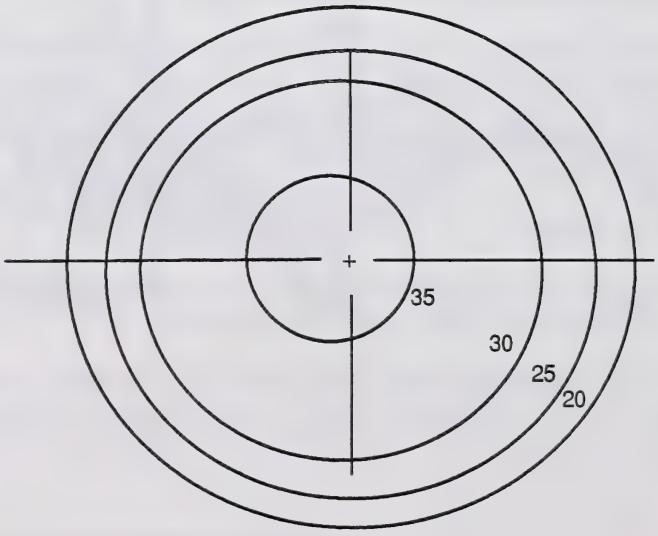


Figure 19: Temperature Gradient with Mixing Vanes (°C)

5.4 Prototype D4

The objective of developing prototype D4 was to simplify unit components and to further reduce the cost and labour time. The improvements intended for D4 would have to be completed without compromising its performance.

Of the three triacs used in the D4 make-up air unit, all were attached to an aluminium plate heat sink penetrating the upstream plenum. The plate conducts heat away from the hottest triac by exposure to the cold intake air. A larger transformer was included to reduce heat build up. This relocation to the upstream wall, away from the heat, helps to extend the service life of the transformer.

5.4.1 Features

Condensation and frost can form on the intake air duct leading to the make-up air unit. Wrapping insulation around the ducts minimized condensation. Inside the make-up air unit was encased with thermal insulation, which extended to the discharge side.

Insulation served both thermal and acoustic functions. In addition to reducing heat loss from the make-up air unit, the insulation reduced fan noise.

5.4.2 Tests and Results

The last prototype was subjected to varying environment conditions and underwent extensive and long term testing. The testing was necessary to determine its reliability and durability when subjected to extreme conditions. For example, a series of tests were conducted under conditions when relative humidity was very close to 100%, and the outdoor air was -30°C. Some hoarfrost became apparent on the unit housing. Within minutes the relative humidity was drastically lowered to 30% and the hoarfrost melted within one half hour after the unit was operating. In another series of tests, the testing chamber was allowed to cool overnight to allow frost to form on the make-up air unit. The make-up air unit was then turned on to assess its start-up characteristics. In this case, the frost melted quickly, but more importantly, it was found that no short-circuiting occurred. These are extreme environment conditions not experienced in the average house.

5.5 Final Features

For safety reasons and to discourage tampering, Canadian Standards Association suggested any access to the unit's internal components should require a tool, such as a screwdriver.

Figure 20 is a schematic of the final prototype make-up air unit.

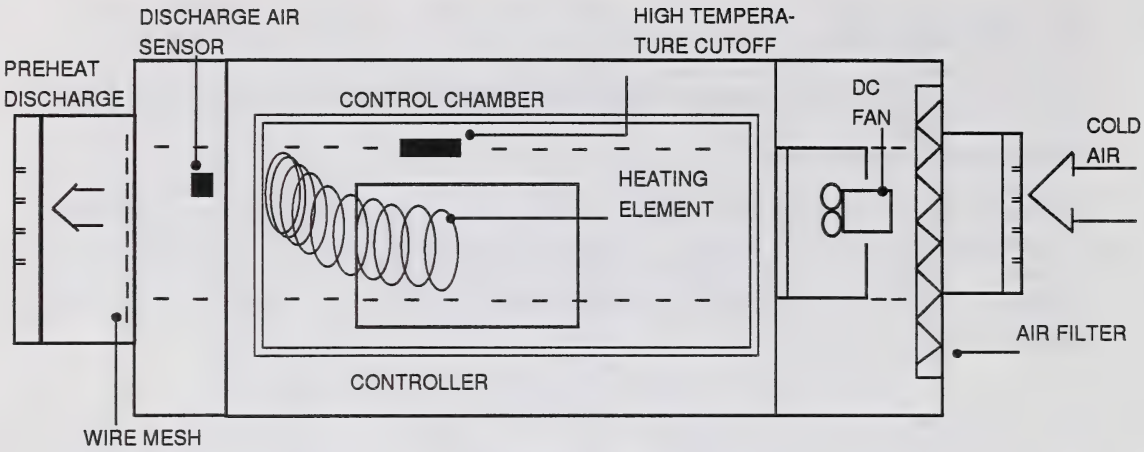


Figure 20: Schematic of the Final Make-Up Air Unit

Certification by the Canadian Standards Association (CSA) ensures the newly designed and constructed equipment meets a developed safety standard and will not cause undue hazard to users. Typical checks by CSA on the make-up air unit involved assessment of adequate spacing between components, with no threat of fire or electrical hazard under normal usage.

The make-up air unit is unique; it is a self-contained, preheat unit with variable temperature and airflow speeds. Therefore, the unit was classified as a make-up air unit, rather than an in-duct heater, even though the unit can be spliced into a duct.

On July 11, 1990 the final prototype of the make-up air unit was submitted for certification to the CSA testing laboratory located in Edmonton. A senior inspector examined the unit and prepared an assessment. Suggestions from CSA are addressed below.

The make-up air unit incorporates a high temperature cutoff set at 38°C. The high temperature cutoff is an adequate safety measure to prevent overheating whenever there is a loss of airflow.

The make-up air unit operates quietly at variable airflow rates, at a temperature range of 13°C to 25°C. The home owner may not even notice the MUA operating. CSA suggested an addition of devices that will convey the operating status of the unit. As a result, indicator lights were incorporated. The lights can be mounted at any convenient location away from the unit.

The make-up air unit has a fan and heating element. In normal installations, the unit can be either spliced into the fresh air supply duct leading to the furnace or installed with an open discharge. In the latter case, a protective screen made of coarse wire material is required to prevent hands or other objects coming in contact with the fan or heating element. Adequate protection is similarly required on the intake side.

The present prototype only simulates the air pressure transducer. The development of the air pressure transducer will be the next logical focus. Without the air pressure transducer, the make-up air unit is regarded incomplete. CSA's approval on an incomplete unit is only partially useful. After the development and incorporation of the air pressure transducer, CSA will undertake a new certification of the completed unit.

6.0 Costs

6.1 Production Cost Estimate

Table 2 tabulates the estimated cost of each component based on varying quantities.

Table 2: Estimated Component Cost of Make-Up Unit (MUA)

Component	100	500	1000
Controller	$195	$170	$155
Sheet Metal*	150	135	125
Fan	75	65	60
Assembly	30	25	25
Heating Element	15	15	10
Testing	10	10	5
Total	$475	$420	$380

* Includes miscellaneous parts such as screen, filters, etc.

An element missing from the above estimate is the cost of the air pressure transducer. The most economic commercially available air pressure transducer is currently selling at approximately $200.00. The lowest air pressure that can be detected by the commercially available unit is in the range of 9 Pa to 100 Pa full scale (0-5 psi). Models able to detect negative pressures down to -5 Pa are higher in cost. The development of an economical air pressure transducer to incorporate into this make-up air unit is considered extremely important if chimney backdrafting is to be prevented. If a remote monitor and controller is considered, it will likely increase the cost of the unit by another $50.00.

6.2 Cost of Installation

The make-up air unit is suitable for reducing backdrafting problems and controlling indoor humidity either by retrofitting into existing homes, or installing in new houses. Installation requires that a hole be cut through the building enclosure for fresh air supply. The make-up air unit must be connected to the fresh air supply duct. At the discharge end, the heated fresh air discharges to the return air duct. The estimated installation costs are broken down as follows:

Install fresh air supply duct through the wall (includes grille, ducting and labour)	$50.00
Install make-up air unit (includes wiring, connections and testing)	$80.00
Connect discharge to return air ducts	$15.00
Install remote monitor and controller	$50.00
Total	$195.00

6.3 Operating Costs

The following sections summarize the anticipated operating cost of the make-up air unit.

6.3.1 Airflow Rates

The operating cost is primarily dependent on the volume of air heated and the duration of the fan operating above the idling speed. Given these variables, it is difficult to determine an exact operating cost. The make-up air unit is not only intended to be run at idle speed, but brings in fresh air whenever a negative pressure in the house is detected. Furthermore, as the negative pressure increases, the airflow rate also increases for balancing.

Indoor negative air pressure is caused by exhaust fans, naturally aspirated, and combustion appliances. The frequency and duration of exhaust fans operation is variable. A rough approximation of the airflow rate of the make-up air unit can be made by estimating the type of activities in a house that require the use of the exhaust fans.

The recommended [CMHC, 1986] airflow rate of the various home appliances for a typical house is found in Table 3. In addition, the measured [CMHC, 1983] airflow rate of 205 sample houses from across Canada is also noted in Table 4. Combustion air requirement was recommended by the BETT program of Energy Mines and Resources Canada.

Table 3: Airflow Rates

	Recommended Exhaust L/s	Measured L/s*	Combustion Air Requirement L/s
Bathroom fan	20	17.2	
Kitchen	70	58.7	
Indoor BBQ	120		
Clothes dryer	65	37.6	100 (natural gas)
Central vacuum	23.9		
Furnace	25		45
Water heater	10		10-15
Fireplace (burning)	110		200
Fireplace (smouldering)	varies		
Airtight wood stove			5
For humidity control		30-50	

* measured airflow rate by CMHC, 1983

Based on the above airflow rates, the estimated daily airflow rates for a family of four are as follows:

Table 4: Estimated Daily Airflow Rate in a Typical House

Location	Activity	Frequency /day	Minutes of use	Airflow rate, L/s	Total litres*
Kitchen	Breakfast	1	10	60	36
	Lunch	1	20	60	72
	Supper	1	30	60	108
Bathroom	Toilet	4	10	20	48
	Shower	2	30	20	72
Clothes dryer		0.6	60	50	108
Central vacuum		0.4	40	30	29
Fireplace (winter)		1	60	100	360
Furnace (winter)		48	5	35	504
Water heater		10	10	10	60
Idle ventilation		1	1440	5	430
				Total	1827

*in '000 litres

The total airflow rate per day is 1,827,000 / (60 minutes x 60 seconds x 24 hour) = 21.2 L/s

6.3.2 Energy Consumption

The make-up air unit consumes varying amounts of electrical energy when operating. In addition to the 4 kW electric resistance heating element, the fan also consumes power.

Chapter 28 of ASHRAE Handbook of Fundamentals, 1981, provides the following equation for estimating energy costs for heating make-up air for a given location:

$$E = \frac{H_L \times D \times 24 \times C_D}{D_t \times k \times V}$$

and:

H_L = 1.1 x airflow rate x temperature difference.

where:

E	=	energy consumption for the estimated period (kW.h)
H_L	=	design heat loss (W)
D	=	degree day (°C), 6302 for Slave Lake
D_t	=	design temperature difference (°C)
k	=	a correlation factor which includes the effects of rated full load efficiency, part load performance, over sizing and energy conservation devices
V	=	heating value of fuel, units consistent with H_L and E
C_D	=	empirical correction factor for heating effect vs.18.3°C degree days

To compensate heat loss due to ventilation, the amount of daily propane consumption and energy cost, can be determined on the design load of 21.2 L/s outside ventilation air flow rate (determined in Section 6.2) and the outdoor temperature of -39°C. The amount of propane based on the preceding equation for E and H_L is:

H_L = 1.1 x 21.2 x 57 = 1.33 kW.h

$$E = \frac{1.33 \times 6302 \times 24 \times 0.7 \times (3600\ kJ/kW)}{57 \times 0.55 \times 50{,}402 \times 0.7}$$

= 545 kg of propane

where: 0.7 = furnace efficiency

If the cost of propane is approximately $0.15/kg, the annual cost is 545 x $0.15 = $81.75.

When using electricity to heat the make-up air, the annual electrical consumption (E) is:

$$E = \frac{1.33 \times 6302 \times 24 \times 0.7}{57 \times 1 \times 1}$$

$$= 2{,}470 \text{ kWh}$$

If the electrical energy cost is $0.0626/kW plus 3.96% municipal tax less 20% income tax, the rate is $0.0519/kW. Annual electrical energy cost therefore is 2470 x $0.0519 = $128.19 per year. Electrical cost for the fan running on idle and occasionally at maximum speed, adds approximately $10.00 per year to operating costs (determined in Section 4). The added electrical operating cost to prevent chimney backdrafting due to additional ventilation is ($128.19 + $10.00) - $81.75 = $56.44 per year. This is a small cost to ensure the health and safety of the occupants.

The amount of intake air required will vary depending on the amount of moisture generated in each house, usage of exhaust fans and combustion appliances. Houses with fewer occupants should consume less additional electrical energy.

6.3.3 Power Consumption Comparisons

From September 21, 1989 to June 8, 1990, electrical energy consumption was monitored for an earlier prototype make-up air unit installed at Gift Lake. The unit consumed 1921 kW of electricity for heating and fan operation during the 260 days (9 months) of monitoring [Lee, 1991]. Based on these operating figures, in one year the make-up air unit would consume:

$$\frac{260 \text{ days} \times 1921 \text{ kW}}{365.25 \text{ days}} = 1368 \text{ kW}$$

Cost of electricity consumed is 1,368kW x $0.0519/kW = $70.99.

The unmonitored summer months of June, July and August would consume electrical energy to maintain an idle speed of 8 Watts, which is only $1.21.

Based on the above calculations and the installed unit at Gift Lake, the make-up air unit is estimated to consume approximately $70.99 + $1.21 = $72.20 per year, or 20¢ per day of electricity, consistent with the earlier estimated cost calculations.

Houses located in major urban areas within Alberta are primarily heated with natural gas, instead of propane. Assuming natural gas in Alberta is approximately $3.00 per giga joule (GJ), the cost of heating the same volume of air as the make-up air unit is calculated at:

$$\frac{3529 \times 3.412 \times \$3.00}{1052 \times 0.7} = \$49.05/\text{year}$$

where:

2470	=	kW h, heat the fresh air
3.412	=	conversion from watt to BTU
1052	=	heating value per cu. ft. of natural gas
0.7	=	furnace efficiency

Houses using natural gas will pay a premium of ($128.21 + $10.00) - $49.05 = $89.16 per year for electrical heating using the make-up air unit to prevent chimney backdrafting and humidity control.

The cost of preheating the fresh air differs from place to place due to different climates, quality of building construction, size and style of building, and the local cost of electricity and heating fuels. Electrical costs are 5.67¢, 7.0¢, and 5.83¢/kWh for cities within Alberta, Ontario, and Quebec respectively. Even though electrical costs are higher in provinces other than Alberta, heating fuel costs are also higher. As a result, the added cost of the make-up air unit will be less than it is in Alberta. In most populated areas within Canada, the additional cost of electricity for preheating is less than $100.00 per year.

7.0 Conclusions and Recommended Future Development

7.1 Conclusions

1. A make-up air unit has been successfully developed which can preheat a variable amount of fresh air and which facilitates the signals from an air pressure transducer (yet to be developed) to compensate for any chimney backdrafting.

2. The prototypes have been tested and then examined by CSA. The component and assembly cost of the make-up air unit is within the range for successful production and marketing. The final unit, including the anticipated air pressure transducer, is estimated to be approximately $550.00, and can be reduced to approximately $450.00 when mass produced.

3. Cost of electricity for preheating fresh air through the make-up air unit is approximately $130.00 per year. The actual cost after subtracting the same amount of heating using natural gas is under $100.00 per year. This modest premium is more than justified by the resulting improvement in indoor air quality and house safety.

4. An air pressure transducer and a remote status indicator are necessary if the unit is to detect negative air pressure to compensate for chimney backdrafting.

7.2 Recommended Future Development

1. The make-up air unit developed in this project is sufficient to provide a varying amount of fresh air into a house. The unit cannot be used to compensate for chimney backdrafting because it cannot detect negative air pressure. Additional work is required for the unit to be fully functional in this area.

2. The logic controller in the make-up air unit is designed to accept a signal from a pressure transducer. The transducer was specifically omitted from this project because its development is sufficiently complex to require additional time and resources. Without the air pressure transducer, only indoor humidity can be controlled by the make-up air unit through a dehumidistat mechanism.

3. Chimney backdrafting can be prevented if inside air pressure is monitored by a pressure transducer. When a negative pressure occurs, the logic controller turns on the supply fan to compensate for the pressure difference. As negative air pressure in the house increase, air intake in the make-up air unit also increases.

4. Based on a CSA suggestion, a visual and audible device should be incorporated into the make-up air unit. A warning signal indicates a malfunction in the unit and can also indicate the nature of the failure. The device should be located where the occupant can easily monitor its operation.

8.0 References

ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., ASHRAE Handbook, Fundamentals, 1981, p. F28.2.

Buchan, Lawton, Parent Ltd. "Improving Make-Up Air Supply Techniques". A report for Canada Mortgage and Housing Corporation, Ottawa, June 1989.

CMHC (1986). "Ventilation: Health and Safety Issues". Canada Mortgage and Housing Corporation, Ottawa, NHA 5888 08/86, p.8.

CMHC (1983). "Ventilation Requirements for Airtight Houses". Report by TES Limited for the Building Energy Technology Transfer Program, Energy Mines and Resources Canada, September, 1983.

Howell-Mayhew Engineering, Inc., "Demonstration, Monitoring and Evaluation of Practical Ventilation Systems for New Alberta Houses". A report for the Innovative Housing Grants Program, Housing Division, Alberta Municipal Affairs, Edmonton, December 1989.

HRAI Technical Services Division Inc., "Residential Exhaust Equipment". A research report for Canada Mortgage and Housing Corporation, September, 1988.

Lee, T. G., (1987), "Condensation in Manufactured Housing". Report for the Innovative Housing Grants Program, Housing Division, Alberta Municipal Affairs, Edmonton, February 1987.

Lee, T. G., (1991), "Mitigating Condensation in Rural Native Housing". Report for the Innovative Housing Grants Program, Housing Division, Alberta Municipal Affairs, Edmonton, October 1991.

Newton, Anthony, "Heating and Ventilation of Modern Housing". A report for the Innovative Housing Grants Program, Housing Division, Alberta Municipal Affairs, Edmonton, March 1987.

Sheltair Scientific Ltd., "The Canadian Residential Duct and Chimney Survey". A report for Canada Mortgage and Housing Corporation, November 8, 1989.

Unies Ltd. "CMHC Guide to Ventilation Systems: Consumer Series". A report for Canada Mortgage and Housing Corporation, March 1988.

Watlow, 12001 Lackland Road, St. Louis, MO. 63146-4039

Domestic Heater Controller Prototype

by: Franco Wu

Description and Operation

The controller is a single board unit that mounts inside the heater unit housing and thus becomes an integral part of the heater unit. The controller receives input signals from the following:

— indoor air pressure,

— indoor relative humidity, and

— air temperature on the downstream side of the unit.

In turn, the controller controls the duty cycle of the heating element and the speed of the fan. As a suitable air pressure transducer is not yet available, the variable pressure signal will be simulated via a control knob on the side of the heater unit. Turning the knob clockwise will increase the speed of the fan.

The major elements of the controller are:

— heater element control logic, and

— fan speed control circuit

1. Proportional Control

   Air temperature in the down pipe is sensed via a semi-conductor heat sensor and fed into a sensor amplifier. Output of the amplifier is an analog signal, which is calibrated to 0.00 Volt @ 0°C and will swing 0.10 Volt/°C. After further processing, this signal eventually drives the heater element to provide the necessary heat to maintain the down pipe air temperature at about 14°C to 20°C. The heater element and fan will be turned on if:

   — temperature is beyond the capacity of the unit, and

   — the fan is shut down if the element and the circuit are open.

2. Fan Speed Control (for these units)

   The fan amplifier responds in proportion to the control knob. The fan will be idling at a very slow speed when the knob is fully counter clockwise and at full speed when the knob is fully clockwise. The idling speed is preset via a trimming potentiometer on board. On the commercial unit, the air pressure controller (transducer) will control fan speed or can be controlled along with the dehumidistat if humidity should rise beyond a set point.

3. Control Logic

The control logic circuit operates in conjunction with the temperature control and the fan speed control circuits to provide:

— a low temperature cut out feature

— a high humidity override and

— a damper control signal

A low temperature cut out was deemed necessary in the event of heater element and/or triac failure. The fan is shut off if:

— down pipe air temperature is below (minimum) 10°C, and

— power on delay timer has expired.

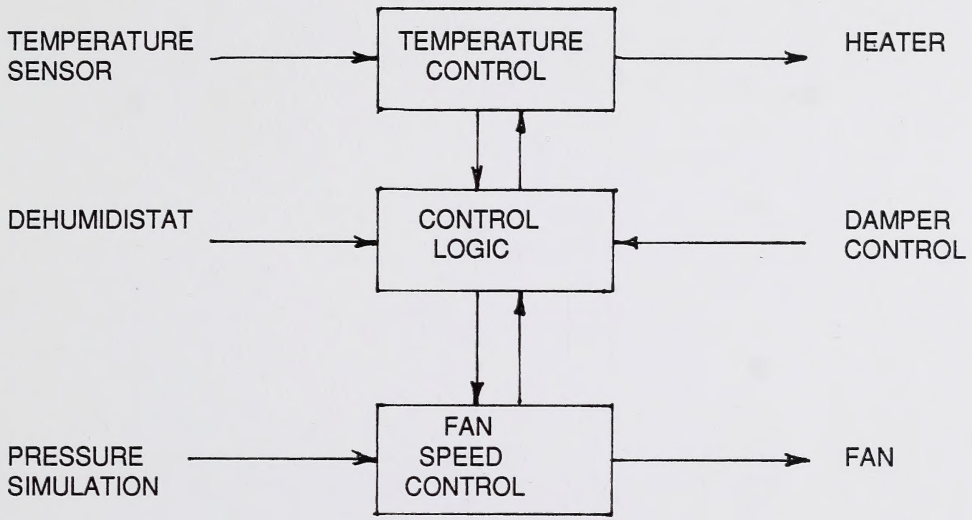
The power on delay timer circuit is necessary because the heater element takes time to reach running temperature when power is first applied. The delay time is now set to approximately 5 minutes. Longer delay is possible by cutting a jumper on the circuit board.

A dehumidistat can be connected to the circuit to provide a high humidity override function. The fan is forced to run at about full speed when a high humidity condition exists, regardless of the setting of the pressure simulation knob. The desired humidity is manually adjusted on the dehumidistat itself. No adjustment is provided in the electronic circuit.

A damper on/off signal is provided via a "comparator" circuit which compares the voltage impressed on the fan motor to a preset level equal to the idling voltage of the fan. When the fan motor voltage is above the idling level, the damper signal line changes from 0.00 Volt to about +15 Volts. This signal is meant to be a control signal only and possess very little drive capability (10 ma). Further buffering will be required for it to drive a damper motor or solenoid.

Various test points, test jumpers and status lights are also provided on the board for diagnostic purposes. The heater is on when the green LED lights up, and the fan is on when the red LED lights up, etc. These diagnostic aids will not be necessary in the commercial version unless we determine it is of value.

Schematic of Control Logic



N.L.C./B.N.C.
3 3286 50150 1288